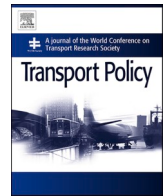




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Vaccination passports: Challenges for a future of air transportation

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ABSTRACT

COVID-19 has been a major setback for air transportation; many airlines had to request for bailouts and the international flights connectivity is only restarting slowly. Accordingly, many aviation stakeholders put hopes into the ongoing process of vaccination, with the expectation that a high degree of vaccination will push the envelope for a return to normalcy. One prerequisite for reviving international air connectivity is the introduction of verification documents, also called “vaccination passports”. These passports, however, come with several challenges which need to be overcome in order to enable recovery. In this study, we propose a framework covering five important aspects and policy challenges concerning the introduction of vaccination passports for a return of aviation, covering the topics: Competition, Epidemiology, Technology, Ethics, and Politics. Neglecting to appropriately address these challenges will likely not only delay the recovery, but possibly miss an important opportunity before new disastrous events appear on the horizon.

1. Introduction

After decades of excitement and two-digit growth rates for air transportation, few people would have expected that large parts of the global system would come to a halt within a period of a few months; leaving an uncertain destiny for one of the biggest transportation industries. Yet, with COVID-19 the singularity happened, leading to flight reductions of more than 90%, airlines filing bankruptcy and asking for governmental bailouts, airports turning into huge aircraft parking places (Abate et al., 2020); see (Sun et al., 2021b) for a literature review on the COVID-19 pandemic and air transportation. While domestic travel has largely resumed in many countries, the international connectivity is still highly affected in many regions of the world. There is an increasing pressure on airlines and governments to restart their international economic ties, together with the desire of people to travel. International human mobility and cross border monitoring of infectious diseases is controlled by the International Health Regulations, the aim of which is the protection and prevention against the spread of a disease worldwide, while reducing the impact on international traffic and trade (Petersen et al., 2021). Under the International Health Regulations, cross-comparisons can be made to earlier epidemics. The International Certificate of Vaccination or Prophylaxis, also called yellow immunization card or Card Jaune, is given to parents to track their child's

vaccines and is a common, globally recognized paper credential. The card lists a person's immunizations together with dates and a health professional's attest. This could possibly be used as a boilerplate not only for design purposes of COVID-19 vaccination passports, but also for addressing the inherent challenges of such a global undertaking (Gruener, 2020).

The direct goals and benefits of an immunity/vaccination passport in the context of air transportation are threefold (Chen et al., 2020). First of all, the passport should protect the traveler. With a sufficient number of shots, the traveler is assumed to be immune, or at least less sensitive to an infection by the virus, leading to a less severe course of disease. Second, the passport should protect the group of fellow travelers who could be contacted, by reducing the risk of transmission during a flight. Third, and maybe the most important goal of the passport at global scale, is to protect the residents at destinations and also at transit stops. There are several earlier studies on immunity passports, but they largely assumed that no vaccine is available. A very strong argument against immunity passports was that these passports might incentivize self-infection (Phelan, 2020). Now we have reached a different state of COVID-19. Several countries have started to provide vaccinations to key groups of their populations and it can be estimated that throughout the year 2021, some of the countries will reach a fully-vaccinated status. Nevertheless, it should be noted that these vaccination efforts are highly

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skewed, with many countries not expected to reach reasonable vaccination scales until 2022 or beyond. In general, the likelihood of introducing such passports for vaccines is high, as there is fundamental scientific evidence for vaccine-induced immunity, compared to the naturally-obtained immunity (Wilson and Flood, 2021).

In this study, we discuss the challenges inherent with the successful introduction of vaccination passports at a large scale. As of now, several stakeholders follow their own ideas and prototypes, which likely leads to highly heterogeneous, uncoordinated results. Many of these projects are related to the aviation sector, given its strong desire to return to normality. Accordingly, we think that the challenges due to vaccination passports for aviation deserves attention by researchers and policy makers. The challenges discussed in this study are grouped into five categories: Competition, epidemiology, technology, ethics, and politics. Our study highlights three major challenges within each of the five categories, together with an outline of how air transportation stakeholders could contribute to successfully overcome these challenges. An overview is presented in Fig. 1. Please note that the localized usage of QR code for check-ins or as access token, as it is used in China and parts of South America, is beyond the scope of our study. The remainder of this study is organized as follows. Section 2 to Section 6 review the challenges regarding competition, epidemiology, technology, ethics, and politics, respectively. Section 7 concludes this paper.

2. Competition

2.1. Passport race

Given the need for restarting travel and economies after the huge impact of COVID-19, several initiatives for providing health certification have been started. Table 1 provides an overview on some of these projects. It can be seen that various entities, including global policy makers such as International Air Transport Association (IATA) and the World Health Organization (WHO), continental agglomerations, as well as individual countries discuss or apply prototypical implementations. Information in such passports will likely have to include the place of issue, date of issue, type of vaccine used, and possibly further information on the verification process. This type of information, ongoing competition, and hasty implementation of different approaches could be compared to opening the Pandora's box of stigmatization and discrimination (Gstrein et al., 2021). Any envisioned vaccination passport program can be successfully realized only if the programs exceed a minimum, critical scale (Gruener, 2020). This scale should not only take into account the view of epidemiologists, but also be considered at the global level. Without sufficient scale of (compatible groups of) passports, the world

Table 1

Overview on selected passport initiatives currently under development.

Name	Description
Travel Pass	A system for managing passengers' test and vaccination history under development by IATA. Several airlines are in trial periods, including Emirates, Korean Air, Qantas, and Singapore Airlines. See https://www.iata.org/en/programs/passenger/travel-pass/
CommonPass	An implementation of a health data app which aims at easing cross-border travel, developed by The Commons Project and the World Economic Forum. See https://commonpass.org/
Digital Green Certificate	A proposal for a system where individuals can prove their test/recovery/vaccination status; with a focus on applicability and unified treatment for people inside the European Union. See https://ec.europa.eu/commission/presscorner/detail/en/ip_21_1181
Smart Vaccination Certificate	A set of standard and recommendations for a framework developed by the World Health Organization. They emphasize specification-focus of the project. See https://www.who.int/groups/smart-vaccination-certificate-working-group
My COVID Pass	A project by the African Union Commission and the Africa Centres for Disease Control and Prevention, with the goal to allow for hassle-free travel across Africa. See https://africacdc.org/trusted-travel/
Green Pass	A vaccination certificate issued by the Israeli Ministry of Health confirming that a person has received a second dose of a vaccine. See https://corona.health.gov.il/en/green-pass/

will see the opposite effect of the original intention: Instead of re-connecting the world, we will see the emergence of “bubbles”. And it can be imagined that these bubbles will be largely cemented along political, ideological, and economical considerations. Accordingly, it is of utmost importance not only to develop passports or passport specifications, but to aim for a concerted solution that helps all people on this planet, without structured exclusion. The accompanying ethical and legislative challenges need to be addressed by policy makers. Currently, the WHO emphasizes the standardization and specification characteristic of its proposal; while the solution of IATA is clearly driven by satisfying the interests of its major customers: airlines. If IATA could significantly expand the number of participating airlines, and at the same time aim to integrate domestic/continental projects, there would be hope that the passport competition can still be taken under control.

2.2. Vaccine race

Vaccines have been developed and verified at a staggering speed

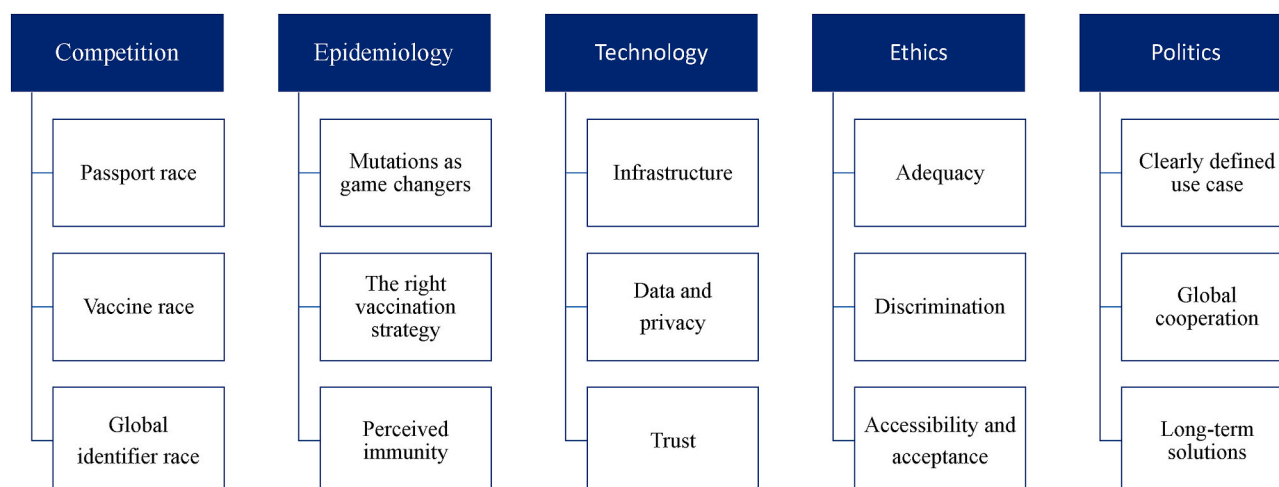


Fig. 1. Framework of challenges for the concerted, successful introduction of vaccination passports in air transportation.

during the past one year, leading to eleven active vaccines in use, 61 in clinical testing, and 251 in development (on March 24th, 2021, data source: COVID-19 Vaccine Tracker); see Table 2 for an overview on the active vaccines. The distribution of these vaccines is far from apolitical (Gstrein et al., 2021). First of all, there has been a strong emergence of nationalism, particularly among the economically developed countries, out of the interest to obtain immunity of their own population first; perhaps a most vivid globalization of “America First”. Second, decisions regarding which vaccines are to be used in a country are not purely evidence based. These decisions are partly driven by the shortage of vaccine supply; yet, the effect appears significantly boosted by ideological considerations. One striking example is the European Union: Several members are in strict opposition towards the question of whether to also use non-European Union approved vaccines, particularly including Russian Sputnik V and three Chinese vaccines. Notably, there are a few exceptions, such as Hungary which has authorized Sputnik V and Sinopharm vaccines for emergency use. Another striking example comes from the Chinese mainland, where only a vaccination with the Chinese vaccines leads to relaxed entry restrictions. The impression arises that scientific data from clinical trials and experiences around the world are not being given sufficient consideration in these tough times of the pandemic. Recent research on mathematical models and simulations found that vaccination efficacies of 80% will significantly improve the chances to return to normalcy; while with vaccination efficacies of 60% travel restrictions may need to remain (Shayak et al., 2021); see also Swan et al. (2020); Brüningk et al. (2020).

Competition among vaccine producers was clearly an advantage for

Table 2

Overview on currently active vaccines against COVID-19 (Source: <https://www.covid-19vaccinetracker.org/>).

Name	Producer	Description
Ad26.COV2.S mRNA-1273	Janssen Pharmaceutical Companies Moderna	Non replicating viral vector, for emergency use in the US. RNA; LNP-encapsulated mRNA, used in Canada, Israel, Switzerland, EU, the US, and the UK.
BNT162b2	Pfizer/BioNTech	3 LNP-mRNAs, approved by the European Commission and in Argentina, Mexico, Saudi Arabia, Canada, Bahrain, the US, and UK.
AZD1222	AstraZeneca/University of Oxford	Non replicating viral vector, used in Argentina, Brazil, Dominican Republic, El Salvador, India, Mexico, Morocco, Pakistan, and the UK.
Sputnik V	Gamaleya Research Institute	Adeno-based, used in Algeria, Argentina, Bolivia, Hungary, Palestine, Paraguay, Serbia, Turkmenistan, UAE, and Venezuela, and registered in Belarus and Russia.
Petrovax	Beijing Institute of Biotechnology	Non-replicating viral vector, for the military by China's Central Military Commission; several countries with emergency use.
Unnamed	Research Institute for Biological Safety Problems, Republic of Kazakhstan	Inactivated virus, used through temporary registration in Kazakhstan.
Sinopharm/W	Wuhan Institute of Biological Products	Inactivated virus, for emergency use in China and the UAE.
Sinopharm/B	Beijing Institute of Biological Products	Inactivated virus, used in Bahrain, China, Pakistan, and the UAE. Several countries with emergency use.
Sinovac	Instituto Butantan/Bio Farma	Inactivated virus, for emergency use in Brazil, China, and Indonesia.
COVAXIN	Bharat Biotech/Indian Council of Medical Research	Inactivated virus, for emergency use in India, Nepal, and Zimbabwe.

the initial development, but it has led to a tremendous, awkward challenge for vaccination use. Given that the intention of vaccine passports for air transportation is to restart international travel, one can anticipate the potential frictions in acceptance of passports based on distinct vaccines, for the same ideological reasons. It has been proposed to provide vaccination passports without the explicit statement of the type of vaccine; yet, it is unlikely that these passports will find wide acceptance across governments. Another important issue is the evidence-based efficacy of vaccines. Overall, recent examples of political games (Gstrein et al., 2021) on the global stage is likely to persist; and the emergence of a global, fact-based deployment of vaccination passports could not be farther away. There is an extreme need for leadership and guidance of international, regulatory bodies. Particularly, IATA and the International Civil Aviation Organization (ICAO), possibly in cooperation with the WHO, need to draft unified, standardized rules for vaccine validity. This has partially happened by the WHO Smart Vaccination Certificate, but more needs to be done. IATA needs to follow these standards; not only by following the interest of its member airlines, but also the interests of the common public. In addition, leaving the design and implementation of passports to individual airlines will very likely lead to nationalism-driven decisions, where large air carriers of a country (which are often state-owned enterprises) follow the expectations of their governments. Therefore, it is of utmost importance for WHO, IATA, and ICAO to not only propose, but also enforce commonly-agreed-upon rules for the restart of air travel under a unified framework of vaccination passports.

2.3. Global identifier race

Digital national identifiers have become reality in many countries, e.g., for purposes of accessing social security services, tax payments, or claiming pensions. Naturally, all such identifiers come with an inherent risk of exclusion: For those individuals who cannot prove their identity, the services are unavailable (Gruener, 2020). A vaccination passport would take such national identifiers to the global level; if it is to be used mainly for the recovery of international travel. In addition, large social media and social network companies have created quasi-identifiers for large parts of the online population. Such data is tremendously valuable, e.g., for the sake of targeted advertisement, user behaviour prediction, and tracking. These two examples show the ambivalence of unique global identifiers: On one hand they are required; on the other hand there is one small step to the evil of abuse. Several aspirants for vaccination passports recently proposed standards from the World Wide Web Consortium, including the use of decentralized identifiers and verifiable credentials. The underlying standards are often not only under-specified, but worse, they come with substantial security and privacy issues (Halpin, 2020). Given that the largest concerns against global identifiers are centered around data privacy and data security, this is a significant setback for these projects under development. Such findings highlight the urgent need of standard verifications by independent experts. These experts should include scientists and professionals from countries of various political orientation and economical development status. Ideally, these standards should be subject to a kind of public peer-review, not hidden behind closed doors. How to perform automatic authentication is another problem concerning the design of a global identifier; recently, iris hashing has shown tremendous potential to be implemented at a large scale (Chaudhari et al., 2020). Nevertheless, all such automated authentication systems will directly trigger data and privacy concerns. These objections need to be solved quickly by the policy makers and relevant stakeholders. These stakeholders include governments, regulatory agencies, civil society groups, and researchers (Gruener, 2020). Airlines have an outstanding role here: Not only because they possess (unique) user data from ticket acquisition, but also because they are the ones that control the physical access to the aircraft, i.e., making crossing the border possible after all. Accordingly, taking airlines on board is probably a key solution towards the use of global

identifiers. The problem is that there should be a concerted effort under the umbrella of IATA, instead of groups or alliances of airlines doing their own thing.

3. Epidemiology

3.1. Mutations as game changers

It should be understood that the scale of COVID-19 provides a huge laboratory for the virus to develop. The destiny of COVID-19 will likely be decided by mutations. Mutations are common, and they often do not affect the function of the virus, or even cause a deterioration in some cases. So-called *variants of concern*, however, cause significant increases in the number of infections in parts of the world. These variants of concern have, for instance, mutations at the receptor-binding domain of the spike protein, tremendously increasing transmission rates (Schlagenhauf et al., 2021). Recent variants of concern include B.1.1.7, B.1.351, and P.1. Their increase in fitness is alarming from multiple perspectives. First, it is not clear up to which degree immunity against the original virus holds for those (or future) variants of concern. Second, the ongoing efforts to vaccinate sub-populations, in the presence of ongoing mutations and competing variants is of extreme brisance for our fight against COVID-19: It is conceivable that variants emerge which are resilient against some of the existing vaccines. Third, with the ongoing reinstallation of international flights around the world - mostly due to economic concerns, these new variants are quickly, yet silently spread around diverse places on our planet. In the past, governments were too slow to react to the emergence of concerns; uncoordinatedly suspending selected flight connections for short amounts of time. Variants often already had reached their destinations before suspensions (Sun et al., 2021a). These concerns altogether might lead to a situation that gets completely out of control, where a chaotic system of competing variants, competing vaccines, and competing passports is prevalent. Therefore, we would argue that, ultimately, it might not only be passports and vaccines that create bubbles, but also variants of concern that let passengers choose destinations based on predominant virus strains. A country-by-country solution is unlikely to resolve the above concerns (Schlagenhauf et al., 2021; Priesemann et al., 2021). Air transportation policymakers have an outstanding responsibility here, given the lack of governmental strategies and implementations. The route network should be adapted not only based on individual countries' decisions on carrier's profit, but there should be a global instance which performs real-time hotspot detection and simulations and provides independent guidance. IATA and ICAO, possibly supported by the World Health Organization, are crucial for this task. The establishment of a global consensus-based intervention framework is an extraordinary challenge. It requires cooperation and synchronization among a wide range of political parties and stakeholders. Nevertheless, a (global) pandemic requires global solutions. Without a critical mass of support, the route network will be fragmented and will have loopholes for passengers to find their ways.

3.2. Perceived immunity

Vaccination passports may suffer a severe problem: The duration and degree of immunity is not well-understood, particularly, due to the short amount of time observable for past vaccinations. Obtaining an understanding of the immunity dynamics with certainty, would require to wait decades; time which is not available to the public (Brown et al., 2020). It can be anticipated that these passports will be put to practice with a limited understanding of the actual risks (Waller et al., 2020). Passports, however, involve binary decision making: an individual is either eligible or ineligible; without intermediate states (Gruener, 2020). Some researchers have argued that the terminology passport is inappropriate and that the term would be better conceptualized as licenses (Persad and Emanuel, 2020). Future outbreaks among passport holders

are likely leading to public frustration and doubts regarding to specific passport or vaccination systems (Larremore et al., 2020). Given that the immunity might be of finite time, there must be the opportunity to revoke specific passports at any time, possibly at a large scale. As a straightforward extension of this thought, the regular renewal of passports at designated intervals (Persad and Emanuel, 2020), the criteria of such renewal and their intervals need to be set by policy makers. Another consequence of the perceived immunity is that airlines and airports are likely to further require social distancing, mask wearing, optimized boarding strategies, and other measures, in order to minimize the worst-case scenario of a super spreading event under perceived immunity. Such an event would subvert all efforts on the creation of sustainable vaccination passports.

3.3. The right vaccination strategy

Another epidemiological challenge is the choice of the right vaccination strategy. The approaches taken worldwide are largely different, and influenced by political agendas, the amount of available vaccines, and the degree of immunity in the population. Several European countries, the United States, and Canada have started to implement vaccination on the elderly, in an attempt to reduce the fatality rate. Some Asian countries, e.g., Indonesia, have put priority on the younger generations, in order to keep the workforce active. Other countries, e.g., China, have chosen to perform vaccination on health personnel, taxi drivers, and delivery people first. In terms of vaccination passports as being used for restarting international travel, the goal would be to perform vaccination on frequent flyers. Notably, this group is not really covered by usually-considered priority groups in any larger countries: Frequent travellers appear in all social groups, including, young and old, independent of the profession, and partially independent of the socio-economic status. Therefore, taking a purely air transport-focused perspective, also in order to avoid the spreading of variants of concern, it is the frequent, long-distance travelers who should get vaccinations soon. Because it is exactly those people who keep the global disease dynamics running. Giving vaccination priorities to long-distance travelers leads to ethical issues; a more feasible possibility might be to enforce vaccination before starting long-distance travel, compared to providing negative tests results only. In addition, an over-proportional charging of frequent/long-distance flyers for financing vaccination passports could be a valid option, given that these traveler groups are generally keener in air transportation recovery and relatively affluent.

4. Technology

4.1. Infrastructure

The design of vaccination passports - at a global scale - comes with many concerns and requirements on the technological infrastructure; taking into consideration that very heterogeneous groups are possibly using these passports. One key question is the decision on whether to use a centralized or decentralized infrastructure and how to manage the actual vaccination data. In this context, several researchers have proposed a design based on blockchains (Angelopoulos et al., 2020; Bansal et al., 2020; Hasan et al., 2020). Simply put, a blockchain is a collection of time-stamped records serialized as blocks. By hash-based back-referencing from a later block to earlier blocks, a high degree of immutability can be achieved. At the same time all transactions can be verified by the public. Accordingly, blockchain-based cryptographic technology has found increasing use in modern transaction-based systems. This is not the first time that blockchains are proposed for addressing COVID-19-induced challenges: When establishing early contact tracing apps, researchers quickly started to keep contact histories stored in blockchains as well (Xu et al., 2020). However, blockchains comes with several security concerns. Some consider them merely a fashionable, new technology, which should be used rather

carefully (Halpin, 2020). Particularly, there needs to be much better understanding of these systems could be used at scale and which other larger societal impacts the adaption of blockchain technologies have; see Kalla et al. (2020) for a recent review of use cases and challenges in face of COVID-19 and Budd et al. (2020) for a review of other digital technologies exploitable for COVID-19.

Another important consideration is whether the actual passport (or access token), is virtually stored as a digital asset or rather a physical (paper/hardware) passport for each user. There are strong arguments for either of the two options. On one hand, a paper-only version could be considered susceptible for fraud and forgery (Eisenstadt et al., 2020). Given the large implications of possessing a vaccination passport, this passport should not be easy to be faked. In addition, a paper-only version, which possibly merely documents the date and type of vaccination, is not easily revoked from the owner. Therefore, digital solutions could be preferred. They come, however, with the limitation that the owner needs to own a reasonably well-setup smartphone and is able to operate the device appropriately. There are many groups for which this assumption does not hold. Despite strong penetration of smartphones in many countries, even these countries have many elderly who are unwilling to or unable to use smartphones. Therefore, committing to digital solutions has a large potential for discrimination and shutting users out. Moreover, it is known that hardware-based access tokens, which would be a third alternative, are prone to flaws at design time, which are discovered only upon a large penetration and then difficult to fix (Chaudhari et al., 2020). Policy makers and operators should consider making hybrid infrastructure and design choices, which allow them to address these challenges. Specifically, for air transportation, given that each passenger needs a ticket, the actual, temporary token could be presented on the flight ticket; which essentially shifts the problem: In this case passengers need to first prove their vaccination status for the airline, possibly in the process of buying a ticket. Here, given the wide range of ticket acquisition opportunities, including webpages and tourism companies with offices, both types of access tokens could be used. Finally, although information technology infrastructure is not a core competency of IATA and ICAO, these organizations should take a leading role here. Instead of letting researchers and software developers create a post-fact situation, which is difficult to repair at a large scale, IATA and ICAO need to set rules and recommendations for the envisioned infrastructure to support vaccination passports. Without such a driving force, the landscape of solutions will be highly scattered and possibly incompatible. Please note that our focus is on air transportation, since it was reported in the literature that air transportation is the key disease spreading medium for pandemic outbreaks. To provide a wider, multi-modal solution, one needs to either take additional stakeholders on board (from ground/sea transportation) or rely on a higher-level institution such as the WHO. Moreover, ICAO processes have shown to be extremely slow, particularly throughout the pandemic. Therefore, policy makers and operators need to find ways to significantly speed up the underlying decision processes.

4.2. Data and privacy

The age of big data and the omnipresent personal data collection by all kinds of smart devices has raised the sensitivity of part of the public to privacy concerns. The trends are more visible in some Western countries. For instance, the German contact tracing app was largely delayed because of an enormous fight on data privacy concerns. These concerns were so much in the focus, that the actual resulting app is considered rather useless, considering its goals of tracing and informing historical contacts in case of an infection. Nevertheless, despite all sophisticated attempts on data privacy, thousands of vaccination and test results could be downloaded from German public healthcare and testing center websites for a short period of time, including names, birthdate, test results, and more. This simple example highlights the crux when dealing privacy: Effective tracing and verification system are super difficult to be

implemented with 100% guarantees of anonymity and privacy, by definition. Companies, especially those associated to the digital economy, often take diametric opposite views: They do not consider data privacy in the first place, but rather build a running system. Once the system is set up, it is often difficult to trace and repair problems regarding already-collected data. One way to support data protection and privacy is that the developed systems are built using open-source technology and rely on the use of open, well-designed standards (Gruber, 2020). If the legislation does not speed up the process of standard and policy making, then very likely private companies (especially airlines, given their strong business needs) will fill this place and develop systems, which are not in the society's best interest, but targeted towards generating profits (Wilson and Flood, 2021). Obviously, data privacy is possibly a conflicting goal with maximizing profits as well. Solutions which provide a trade-off are desirable and technically feasible (Zhang et al., 2020).

4.3. Trust

Passports come with huge benefits to the owners. Accordingly, some individuals or businesses could be incentivized to perform forgery and illegal markets could open up (Persad and Emanuel, 2020). Not only does fraud concern the creation of technically-faked documents, but also the issuing of true documents by unethical physicians or companies. First cases of malpractice have been reported in some countries, including Philippines and India (Deguma, 2021). Notably, there are concerns beyond the purely legal problem involved in fraud. If a society does rely on the validity of vaccination passports, the taken measures of caution will be gradually reduced. This environment makes it naturally much easier for a virus to spread, without being detected. Therefore, the technical body driving the design and implementation of vaccination passports should incorporate appropriate security measures right from the beginning, including the use of biometric information and cryptography, with reasonable procedures for verification. Again, the use of open-source technology can enhance the trust of the society into passport systems (Zhang et al., 2020).

5. Ethics

5.1. Adequacy

One fundamental aspect in the discussion regarding ethics of vaccination passports is that the different treatment of groups based on epidemiological risk needs to be proportionate to the risk to be ethically acceptable (Voo et al., 2021). This translates into the question of whether the benefits of introducing such passport outweighs the social and ethical risks induced. In case of COVID-19, with varying and often seemingly uninformed decision making of policy makers, another fact should not be neglected: There are people who solely interpret the given rules as being best served by others while themselves not following any (Brown et al., 2020). Such viewpoints need to be taken into consideration as well, by merging expertise from psychologists, epidemiologists, and others. One needs better modeling tools, to understand and forecast the effect of policy implications on the population; see (Kass, 2001) regarding an ethics framework for public health. In the end all decisions are about risks.

5.2. Discrimination

Discussion on oppressive systems is prevalent in our society, concerning adverse effects such as racism, sexism, and homophobia (Liz, 2021). With the distribution of first vaccination patches, a profound discussion started: Should a vaccine come with significantly increased freedom, compared to those who are not vaccinated (de Miguel Beriain and Rueda, 2020)? In terms of application in air transportation, this question is clearly answered to a yes, since the sole purpose of the

vaccination passport is just to enable international connectivity. Without a distinction into vaccinated and non-vaccinated, the vaccination passport will not have any direct benefits for airlines and the society. Most concerns are being raised due to existing research on how group processes turn tribal easily (Brown et al., 2020). Discussions on discrimination are driven by historical comparisons, for instance, the Deep South in the United States during the mid-1800s, where the yellow fever was used to justify discrimination against immigrants and non-white groups (Olivarius, 2019; Liz, 2021). While these concerns are undoubtedly reasonable historically, it seems at least questionable, whether the existence of passports leads to a long-term discrimination. In fact, it is argued that unlike most other social disparities, those coming with immunity are likely a transitional effect towards wide vaccination or established herd community (Hall and Studdert, 2020). Intensive care needs to be taken for groups which cannot be vaccinated for medical, religious, or other to-be-decided exemptions. These groups may be vulnerable even once every individual had an opportunity to get vaccinated. Finally, the expected effect of society division into mutually exclusive groups, i.e., vaccinated/not-vaccinated or sero-positive/negative, is very likely unavoidable, even without the explicit establishment of vaccination passport (de Miguel Beriain and Rueda, 2020; Persad and Emanuel, 2020). Accordingly, we feel that the goal of a fair and equitable society should not be used as a thought-terminating cliché against vaccination passports. Instead, policy makers need to aim for accessible vaccines and documentations for the whole population.

5.3. Accessibility and acceptance

All effort on planning vaccination passports would be wasted without public acceptance. We are living, however, in an era of suspicion about data-collecting apps and potentially-biased discussion in social bubbles (Eisenstadt et al., 2020). A poll on medical students in the United States revealed that about one in four is hesitant to get vaccinated against COVID-19 (Lucia et al., 2020); similar findings have been reported for medical staff (Dror et al., 2020). The impact of hesitance of health-related population is twofold. First, given their potential proximity to other vulnerable people, e.g., inside hospitals, these non-vaccinated employees and students could pose a potential threat. Second, one would assume that people with medical background do well understand the necessity of vaccination against COVID-19. Therefore, it is concerning that resilience among these groups is relatively high. One possible argument for such counter-intuitive behaviour is that COVID-19 has put a magnifying glass on the fact that we are living in the age of infodemics (Gallotti et al., 2020), where few people or organizations intentionally spread fake news and false scientific claims, mostly under exploitation of social networks (Bin Naeem et al., 2020; Zarocostas, 2020). Therefore, in order to increase acceptance by the population, it is of utmost importance to perform an adequate and more localized public education (Blanchard et al., 2019), tailored to specific audiences (Udow-Phillips and Lantz, 2020). Some researchers have highlighted that the yellow fever's vaccine is not 100% successful either and much more deadly than COVID-19; yet, the yellow card was widely accepted as official certification (Petersen et al., 2021). Such arguments are encouraging when hoping that the world can restart travel under the effective usage of vaccination passports. As for the role of airlines, since the target audience is (frequent) flyers, one approach could be to let airlines make vaccination offers to their clients; possibly in coordination with WHO and ICAO/IATA.

6. Politics

6.1. Global cooperation

History can teach important lessons on the interactions between global health and international relations. For instance, political

decisions regarding yellow fever were often dominated by economic, religious, and foreign policy interests; leading to diplomatic tensions among stakeholders (Vanderslott and Marks, 2020). In fact, it should be noted that the motivation for raising the International Health Regulations on yellow fever was - just as COVID-19 - be driven by the tremendous risks of air transportation. Accordingly, politics - not only researchers - should acknowledge the important role of air transportation in our society for the spread of infectious diseases (Tuite et al., 2020). Given that air transport is the major form of international travel, there needs to be global cooperation. The 193 members of the United Nations should reiterate the ultimate goal of the International Health Regulations: Strengthening the preparedness and control of disease outbreaks, while deterring members from imposing arbitrary travel restrictions. Therefore, politicians and policy makers need to step forward and aim for cooperation, instead of nationalism-driven competition. It has been shown based on data for the United States that the public views on immunity certificates are not divided across typical political lines (Hall and Studdert, 2021). On one hand, this observation is striking; given the starkly politicised discussion of many topics in the United States. On the other hand, it might only be a matter of time, until one party finds the opportunity to form a position in public (Hall and Studdert, 2021). In summary, the year 2020 revealed a strong dominance of national responses and mitigation strategies, partially driven by ideological considerations. Global organizations, including the WHO and European Union, have been marginalized, and the results are a highly-visible compartmentalization of the world into distinct states (Gstrein et al., 2021). While the articulated goal of the last centuries was to move closer together, exploiting synergies and economies of scale, COVID-19 has foiled decades of work with unforeseeable long-term consequences.

6.2. Clearly defined use case

One urgent goal for politicians and policy makers is to define the exact use case of vaccination passports. While the initial driver for these passports is rooted in air transportation and international connectivity, practice might lead to other applications as well, particularly as long as individual countries are not vaccinated to a degree of 100%. Examples include the use of these passports in domestic travel (including train and public transit), access for employees to office buildings, or even the controlled access to public areas. Depending on the ultimate use case, the challenges coming with vaccination passports vary and the importance is possibly shifted to selected challenges. Given the huge impact of establishing a working, global vaccination passport, one should aim to avoid that too many local passport systems emerge; or, in the worst case, competing passports based on the use case.

6.3. Long-term solutions

Throughout the COVID-19 pandemic, the impact of different political systems on epidemiological decision making has become strikingly clear. Specifically, pluralistic, democratically-controlled countries have revealed slow responses. Other countries, e.g., China, have literally blown-away the pandemic by now and are back stronger than before. The drivers for such differences are beyond the scope of this transportation-focused study. Yet, it is due to raise a few possible problems which are happening in the countries that failed to properly address COVID-19. One core challenge of this pandemic is to identify and fight the reasons for the denial of scientific method for many people involved (Pavakis, 2020). This particularly includes politicians. Decisions nowadays in political democratic systems are being made with short-term sight. Essentially, always looking for the next legislative period and how to get re-elected. The lack of long-term view and long-term commitment leads to perverse delays and decisions. For instance, in Germany, many regional elections and one federal election is due in 2021. The major ruling parties are so afraid of making hard

decisions - which are absolutely necessary based on epidemiologists - that they rather continuously promise rule relaxations and soon-to-take-place holidays, instead of efficiently tackling the roots of the problem. Not only introducing vaccination passports, but also the successful handling of the pandemic requires long-term thinking and long-term decision making.

7. Conclusions

Early in the year 2020, several organizations proposed the idea of immunity passports; which can be understood as a prequel to vaccination passports discussed in this study. One of the largest concerns against immunity passports one year ago was centered around one ethical question: Does the sole existence of an immunity passport provide a sufficiently-large incentive for parts of the population to deliberately force self-infection? Several researchers have answered this question to the positive (Hall and Studdert, 2020; Hemel and Malani, 2020). An adequate paragon might be so-called chickenpox parties: Parents hold parties for their children in an attempt to allow their children to build immunity before reaching adulthood. The motivation for parents is that symptoms at adulthood can be much severer; see (Malm and Navin, 2020) for a recent discussion on the ethics of such chickenpox parties. Similar lines of thought can be applied to COVID-19. Especially younger people could be tempted to perform intentional self-infection, given seemingly much weaker symptoms for people at young ages, just in order to reach a (formal) status of immunity (Hemel and Malani, 2020). Since COVID-19 is more lethal and unpredictable, compared to chickenpox, the actual magnitude of such self-infections is hard to predict. Another ethical concern is that a person who is not (yet) infected with the virus should not be considered a health threat just because of the lack of immunity (Voo et al., 2021).

The widespread application of seroprevalence tests for informed policy and decision making on immunity passports depends on another critical factor: the reliability and accuracy of tests (Phelan, 2020). Generally, it should be accepted that no certification or test is perfect, particularly involving a virus discovered only recently (Persad and Emanuel, 2020). Test accuracies need to be much better understood, especially if they are reasons for making decisions involving the restriction of fundamental human rights; see (Lisboa Bastos et al., 2020). A related question is: how were specific testing regimes able to reliably distinguish between past infections from SARS-CoV-2 and other known human coronaviruses? In addition, the question of how many re-infections can take place is not fully answered in the scientific literature; with only a few reported and proven cases of reinfections worldwide (Iwasaki, 2020). A final argument against immunity passports was that there are simply not enough recovered individuals; so why to bother about the effect of immunity passports, especially in light of the above concerns? Accordingly, none of the relevant public bodies advocated the use of immunity passports; this includes the World Health Organization, the European Centre for Prevention and Control, the International Air Transport Association, and the International Civil Aviation Organization.

Given that vaccines are available now, the situation is significantly different. This study has highlighted the inherent challenges coming with the introduction of vaccination passports towards the revival of air transportation. The key factor for success is a swift (in terms of reaction time), well-informed (in terms of being built upon scientific facts), and consensus/majority-driven (in terms of cooperation) solution to this problem. As these three objectives are partially conflictive, there is no easy way towards an ideal solution. In these months, one can observe how passports are mainly realized by individual countries, with a particular focus on developed countries. These countries face an increasing pressure, given the recent advances in vaccination efforts. As of now, it seems that the near-term future could be one of bilateral agreements. This fragmented, island-like solution is to be avoided. Accordingly, we propose that all involved stakeholders, including

governments, airlines, and global organizations, come together and push the dissemination of common passports. While it is unlikely to reach a final consensus among all key players, there is a need to discuss and agree upon a greatest common divisor in a sustainable aviation future with vaccination passports.

In this study, we have not discussed the issue of financing vaccination passports and their infrastructure. In general, making passengers pay directly for their passports, may lead to issues concerning equality and could possibly reduce the realized demand for air travel. On the other hand, making airlines pay for the vaccination or the vaccination passports will likely lead to the increase in ticket prices, which are in turn paid by the passengers. We advocate a shared financial backing of the system by governments and airlines, and raise this question as a very interesting direction for future research, which could consider the perception and preferences of passengers and other stakeholders.

Finally, all decisions involved are about risks and finding working compromises. We argue that it is important for all policy makers that a reaction is ensured before the public consensus is formed, based on social networks and other bubble-induced discussions. If the time window of global coordination efforts is missed, surely enterprises and other stakeholders will be joining the golden business (Chen et al., 2020). These stakeholders, in the absence of further regulations, will follow their own rules and interests, which are not necessarily in the best interest for the society. This highlights the outstanding role of international organizations, some of which indicated above, in taking a lead role in policy discussion, coordination, and regulation. The leadership needs to anticipate the incentives of different stakeholders including airlines' loss avoidance/profit seeking, individual countries' regaining/maintaining international air transport connectivity, and citizens' and businesses' mobility.

Author statement

Xiaoqian Sun: Conceptualization, Methodology, Writing – original draft preparation. Sebastian Wandelt: Conceptualization, Writing - Reviewing & Editing. Anming Zhang: Conceptualization, Validation, Writing - Reviewing and Editing

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